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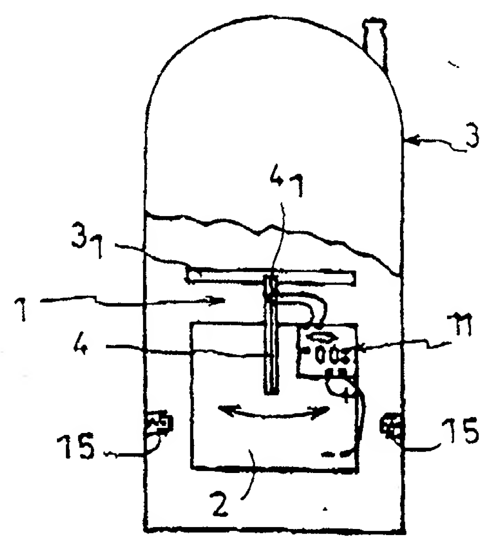
(54) Piezoelectric device for charging an electrical energy accumulator powering an object subjected to vibrations.

(57) - The object of this invention relates to a piezoelectric device for charging an electrical energy accumulator (2) powering an object (3) subjected to accelerations, with the device comprising:

- at least one piezoelectric element (4) connected to the object (3),
- a mass acting on the piezoelectric element so as to cause the occurrence of electric charges when the object is subjected to acceleration,
- and an electrical circuit (11) for converting the charges that occur as a result of the oscillation of the piezoelectric element into a charging current for the electrical energy accumulator (2), with the circuit comprising at its input a rectifier stage that delivers d.c. voltage.
- Pursuant to the invention, the conversion circuit (11) comprises a d.c.-d.c. converter interposed between the rectifier stage and the accumulator (2) that has a constant and purely resistive input impedance and that delivers at its output an average current substantially proportional to the square of the voltage delivered by the rectifier stage.

FIG_1



This invention relates to the technical field of systems for charging an electrical energy accumulator that powers an object in the general sense subjected to vibrations or shocks.

The object of this invention is especially advantageously used in the field of electrical items whose operation requires the use of an energy accumulator, these items being of a portable nature or operating in isolated places while being subjected to vibrations or shocks. By way of non-limiting illustration, the invention can be used in portable microcomputers, radio communication equipment, such as telephones and telecopiers, timers, radio stations, or lighted buoys.

One of the major problems that arises with these types of objects is their energy autonomy of relatively short duration.

To attempt to solve this problem the state of the art has proposed a first solution consisting of using photoelectric elements that generate charging currents depending on the intensity of natural or artificial illumination. This type of charger is used especially with items such as watches or calculators.

This technical solution provides for the generation only of small currents unless large-area photoelectric panels are made, which is not always possible because of the portable nature of the objects. It also seems that the efficient generation of charges depends on a suitable orientation of the collectors in the field of a light source of sufficient intensity, so that this technical solution can not be used to equip various portable objects that may be used in the absence of a light source.

Another solution known in the state of the art is to utilize, with the help of thermoelectric means, the temperature difference between the heat of the human body and the ambient temperature. Other than the fact that this type of solution has a low yield, the principle itself of this technique limits its applications practically to wristwatches.

Another solution is known that consists of utilizing the energy of mechanical motions that are induced in an inertial component of the object by natural motions associated with the transport of this object. A device is also known that is intended to convert the motions by electrodynamic

means, comprising a magnetized microrotor moving inside a coil of electrically conductive wires. The vibrations are applied to the object, and consequently to the microrotor so as to obtain the occurrence of an electrical current, which after having been rectified and stored in a capacitor is transferred to a battery. It seems that the yield of this device is still low, and that it is very complex and thus fragile. It is found in practice that such a technical solution is limited essentially to clock applications that require limited power of the order of a microwatt.

In other regards, the document SU-A-618 717 discloses a device for charging an electrical energy accumulator comprising a piezoelectric wafer, one end of which is connected to the object and whose other end supports a mass. The wafer is connected to a circuit that converts electrical charges that occur when the object is subjected to acceleration. The charge conversion circuit is composed of a rectifier stage. This solution has the same drawbacks as those enumerated above to the extent that the power recovered is still of the order of a microwatt, which limits the applications of this type of device.

The present invention accordingly intends to remedy these drawbacks enumerated above by proposing a device suitable for charging an electrical energy accumulator that powers an object in the general sense that is subjected to accelerations, and that is capable of generating electric power, for example of the order of several milliwatts, sufficient to permit charging the said electrical energy accumulator.

Another object of the invention is to provide a device for charging an accumulator of electrical energy that provide high reliability and simplicity of manufacture, while providing the benefit of not making heavy the objects equipped with the device pursuant to the invention.

To achieve these objectives, the device pursuant to the invention comprises:

- at least one piezoelectric element connected to the object, capable of oscillating in at least one degree of freedom,
- an oscillating mass acting on the piezoelectric element so as to cause the occurrence of electric charges when the object is subjected to acceleration,

- and an electrical circuit for converting the charges that occur as a result of the oscillation of the piezoelectric element into a charging current for the electrical energy accumulator, with the circuit comprising at its input a rectifier stage that delivers d.c. voltage.

According to the invention, the conversion circuit comprises a d.c.-d.c. converter interposed between the rectifier stage and the accumulator that has a constant and purely resistive input impedance and that delivers at its output an average current substantially proportional to the square of the voltage delivered by the rectifier stage.

Various other characteristics are found in the description below, with reference to the attached drawings, which by way of non-limiting examples show embodiments and implementations of the object of the invention.

Figure 1 is a schematic view showing an applied example of a piezoelectric device pursuant to the invention for a portable object.

Figure 2 is a general view showing a characteristic detail of the device pursuant to the invention.

Figures 3 and 4 are diagrams explaining two variants of embodiment of a conversion circuit pursuant to the invention.

Figure 5 is a schematic view showing another example of embodiment of a piezoelectric device pursuant to the invention.

As shown more precisely in Figure 1, the device 1 pursuant to the invention is intended for charging an electrical energy accumulator 2 that powers an object 3 in the general sense intended to be subjected to vibrations, to shocks, or generally to accelerations. Traditionally, the object 3 has an electrical energy accumulator 2 such as a battery intended to power a specific electrical circuit that performs suitable functions depending on the nature of the object.

The device 1 pursuant to the invention for charging the accumulator 2 comprises at least one piezoelectric element 4, composed in the example shown of a wafer connected at one of its extremities 4_1 to the object 3. In the example illustrated, the extremity 4_1 of the wafer is mounted

on a plate 3_1 that is part of the object 3. The piezoelectric wafer 4 comprises a pair of armatures 5 and 6 placed on its principal opposing faces so that charges of opposite sign occur on the armatures under the influence of a force, and accordingly a potential difference proportional to the applied force. The piezoelectric wafer 4 is preferably constructed using a polarized ferroelectric ceramic.

Of course a wafer 4 made up of a combination of piezoelectric lamellae can be used, so as to constitute a bimorphic or polymorphic assembly, either parallel or serial. In the same way, it is conceivable to make the wafer from a flexible or elastic material on which are mounted one or more ceramics. In other respects, it should be considered that the piezoelectric element can be made in a form different from a wafer. Thus, an assembly of ceramics functioning by tension-compression can be utilized. It is also conceivable to make a system with lever arms acting on the piezoelectric element to permit modification of the rigidity of the system thus produced.

The device pursuant to the invention also comprises a mass 7 suitable for acting on the piezoelectric element 4 so as to cause the occurrence of electrical charges on the armatures 5 and 6 when the wafer is subjected to accelerations resulting from vibrations of the object. As shown more precisely in the example illustrated in Figure 2, the oscillating mass 7 is mounted as an overhang on the wafer 4 while being anchored at the free extremity 4_2 of the wafer opposite to that 4_1 anchored to the object 3. The mass 7 is preferably composed of the accumulator 2 so that the weight of the object 3 is not increased by the incorporation of an additional mass. If the piezoelectric element is not made in the form of a wafer, the mass 7 is mounted so as to act on the piezoelectric element.

The piezoelectric wafer 4 thus works by flexing while supporting a mass 7 mounted as an overhang, permitting flapping motions of relatively large amplitude to be obtained, for example of the order of several centimeters. The wafer 4 thus equipped is accordingly able to oscillate according to at least one given degree of freedom considered in a preferential plane of flexing P. The wafer 4 is suitable for presenting low oscillation frequencies in order to coincide best with the tenor of the transport stresses, also of low frequency. For example, the wafer 4 is of dimensions to offer an oscillation frequency between 1 and 20 Hz, and preferably between 5 and 10 Hz. In the same way, the oscillating mass 7 weighs between 30 and 500 grams, and preferably of the order or 100 grams.

The device pursuant to the invention also comprises an electric circuit 11 that converts charges that occur at the terminals of the wafer 4 because of its oscillation, into a charging signal for the battery 2. The piezoelectric element 1 pursuant to the invention thus provides for charging the battery 2 by recovery of the electrical charges due to the acceleration motions of the wafer 4 and following the various shocks or vibrations that the object undergoes during its transport or use.

In the example illustrated more precisely in Figure 2, the conversion circuit 11 has a rectifier circuit 12 that permits the charges obtained to accumulate for one entire period as the oscillating motions generate opposite electrical fields in each half-period of oscillation of the wafer. The rectifier circuit 12 delivers an output voltage Ve that is applied to the input of a circuit 13 designed to convert the rectified signal into a charging current. To this end, the conversion circuit 13 has an input impedance 13_1 suitable for the electrical characteristics of the wafer 4 and a current generator 13_2 that provides for charging the accumulator 2.

As shown more precisely in Figure 3, the conversion circuit 13 constitutes a d.c.-d.c. converter interposed between the rectifier stage 12 and the accumulator 2. It should be understood that the circuit 13 is suitable for converting the d.c. signal delivered by the rectifier 12 into a d.c. current i, in other words unidirectionally variant, so as to charge the accumulator 2 at a voltage imposed by the latter, regardless of the voltage delivered by the rectifier stage.

According to the invention, the converter 13 should have a purely resistive input impedance whose value is constant regardless of the amplitude of the input voltage Ve delivered by the rectifier stage 12. The value of this input resistance is determined on the one hand by the mechanical characteristics of the mass-spring system equivalent to the piezoelectric element equipped with the mass, and on the other hand by the characteristics of the displacements to which the object is subjected. Actually, it should be considered that the value of this input resistance is calculated so as to obtain an overvoltage factor determined for the mechanical resonator formed by the piezoelectric element. The overvoltage factor and the resonant frequency of such a resonator are optimized for a given form of excitation spectrum, to obtain a fixed fraction of the maximum power defined by the value of the mass 7 and the intensity of vibrational excitation for a minimal displacement of the wafer 4.

For an excitation frequency range below 20 Hz and limiting ourselves to an available power, for example equal to 0.9 times the maximum power, the overvoltage factor can assume values below 10 with a resonant frequency close to 15 Hz. Preferably, for uniform excitation between 1 and 12 Hz, the overvoltage factor will be of the order of 8 with a resonant frequency of approximately 9 Hz. The value of the input resistance is then deduced from the mechanical and electrical characteristics of the wafer 4, and from the values of the overvoltage factor and resonant frequency.

The converter 13 has another characteristic, which is that of delivering at the output, except for losses, an average current i essentially proportional to the square of the input voltage Ve. The unidirectional current i supplies the accumulator 2 at a voltage imposed by the accumulator 2.

The converter 13 pursuant to the invention is composed of a resonant power supply that on the one hand has a purely resistive input impedance of constant value, and on the other hand delivers an average current proportional to the square of the input voltage Ve. The structure and performance of a resonant power supply are known and described, more particularly, in the book ALIMENTATION A DECOUPAGE - CONVERTISSEURS À RÉSONANCE - J.P. FERRIEUX & F. FOREST, Editions MASSON, 2nd Edition, 1994,. The following description, with reference to Figure 3, describes succinctly a resonant power supply applied to charging a battery 2.

The resonant power supply 13 has two electronic switches K_1, K_2 mounted in series between the output terminals of the rectifier stage 12 that delivers the input voltage Ve. The switches K_1, K_2 are controlled in function by a control circuit 20 driven by the input voltage Ve, so that the control frequency of the switches is proportional to the input voltage Ve.

The resonant power supply also has two rectifiers, such as two diodes D_1, D_2 mounted in parallel, respectively, with the switches K_1, K_2. Two capacitors C_1, C_2 of the same value, mounted in series, are connected between the output terminals of the rectifier stage 12. An inductance L, mounted in series with a rectifier circuit 21 supplying the battery 2, is connected on the one hand to the midpoint of the diodes D_1 and D_2 and of the switches K_1 and K_2, and on the other hand to the midpoint of the capacitors C_1, C_2.

The rectifier circuit 21 is formed by a bridge of four diodes D_A-D_D whose [*illegible*] branch has the battery 2. In a conventional manner, switches K_1, K_2 are controlled to function alternately. Thus, when the switch K_1 is controlled in conduction mode, while at the same time the switch K_2 is blocked, the current passing through the inductance L consists of two sinusoidal half-waves whose frequency is determined by the values of the inductance L and of the capacitors C_1 and C_2. During the first half-period, the conduction is provided for by the switch K_1 and the current feeds the battery 2 through the diodes D_A and D_D. During the second half-period, the conduction is provided for by the diode D_1 and the switch K_1 can then be open. The current then feeds the battery 2 through the diodes D_B and D_C. At the end of the complete period, neither the switch K_1 nor the diode D_1 conducts, and the switch K_2 can then be closed. Operation identical to that described above is then produced.

The resonant converter described above constitutes a circuit optimized for recovering the electrical energy delivered by the piezoelectric element.

Figure 4 illustrates another variant of embodiment in which the winding L is composed of the leakage inductance of the primary of a transformer T whose secondary winding feeds the rectifier circuit 21. The use of a transformer T permits adapting the voltages to the charging voltage for the battery 2.

According to a beneficial characteristic of the invention, the wafer 4 is limited in its oscillating motion by the use of two bumpers 15 placed in the plane of flexing P, on both sides of the wafer 4. For example, the bumpers 15 are placed so as to come into contact with the oscillating mass 7. Preferably, the bumpers 15 are of an elastic nature, permitting the recovered energy and the oscillation frequency of the mass 7 to increase. Such an arrangement permits the available electrical power to be increased.

In the example illustrated, the piezoelectric wafer 4 is mounted so as to operate by flexing in a plane P perpendicular to its principal faces composed of the electrodes 5 and 6. Of course it is conceivable to make a piezoelectric element formed of at least two piezoelectric wafers mounted so that each has a different plane of flexing. Thus, it would be conceivable to mount on the piezoelectric wafer 4 another piezoelectric wafer displaced by 90° whose preferential plane of flexing would be parallel to the plane of the armatures, that is to say perpendicular to the plane of

flexing P. Such an arrangement has the advantage of being able to recover the energy of oscillations of the mass 7 from displacement in the two directions indicated above.

As shown more precisely from the assembly illustrated in Figure 1, the device 1 is sensitive to stresses of translation along a horizontal axis in the plane of the page. Figure 5 illustrates an assembly in which the device 1 is sensitive to stresses of translation along the vertical axis. In this example of embodiment, it should be noted that the accumulator 2 is supported by two wafers 4 supported as overhangs by the plate 3_1.

The invention is not limited to the examples described and shown since diverse modifications can be applied to it without exceeding its scope.

Claims

1 - Piezoelectric device for charging an electrical energy accumulator (2) powering an object (3) subjected to accelerations, with the device comprising:

- at least one piezoelectric element (4) connected to the object (3), capable of oscillating in at least one degree of freedom,
- an oscillating mass (7) acting on the piezoelectric element so as to cause the occurrence of electric charges when the object is subjected to acceleration,
- and an electrical circuit (11) for converting the charges that occur as a result of the oscillation of the piezoelectric element into a charging current for the electrical energy accumulator (2), with the circuit comprising at its input a rectifier stage (12) that delivers d.c. voltage,

characterized by the fact that the conversion circuit (11) comprises a d.c.-d.c. converter (13) interposed between the rectifier stage (12) and the accumulator (2), that has a constant and purely resistive input impedance and that delivers at its output an average current essentially proportional to the square of the voltage delivered by the rectifier stage.

2 - Device pursuant to Claim 1, characterized by the fact that it includes two bumpers that limit the displacement of the piezoelectric element (4).

3 - Device pursuant to Claim 2, characterized by the fact that the bumpers (15) are of an elastic nature, permitting the converted electric power to be increased.

4 - Device pursuant to Claim 1, characterized by the fact that the d.c.-d.c. converter (13) has a resistive input impedance whose value is determined as a function of the mechanical characteristics of the piezoelectric element combined with the mass.

5 - Device pursuant to Claim 1 or 4, characterized by the fact that the d.c.-d.c. converter (13) is composed of a resonant power supply comprising:

- two controlled electronic switches (K_1, K_2), each of which in parallel has two rectifiers (D_1, D_2) mounted in series between the output terminals of the rectifier stage (12),
- two capacitors (C_1, C_2) mounted in series between the output terminals of the rectifier stage (12),

- an inductance (L) combined with a rectifier bridge (21) powering the accumulator (2) and mounted between the midpoints of the switches (K_1, K_2) on the one hand and the capacitors (C_1, C_2) on the other hand.

6 - Device pursuant to Claim 5, characterized by the fact that the electronic switches (K_1, K_2) are controlled at a frequency proportional to the input voltage (Ve) of the converter delivered by the rectifier stage.

7 - Device pursuant to Claim 6, characterized by the fact that the winding (L) constitutes the leakage inductance of the primary of a transformer (T_1) whose secondary winding feeds the rectifier bridge feeding the accumulator (2).

8 - Device pursuant to Claim 1, characterized by the fact that the piezoelectric element (4) is a polarized ferroelectric ceramic.

9 - Device pursuant to Claim 1 or 8, characterized by the fact that the piezoelectric element (4) has an oscillation frequency between 1 and 20 Hz, and preferably between 5 and 10 Hz, and is equipped with a mass weighing between 30 and 500 grams, and preferably of the order of 100 grams.

10 - Device pursuant to Claim 1, characterized by the fact that the piezoelectric element (4) and the mass (7) constitute a mechanical resonator whose overvoltage factor is below 10, and preferably of the order of 8.

FIG_1

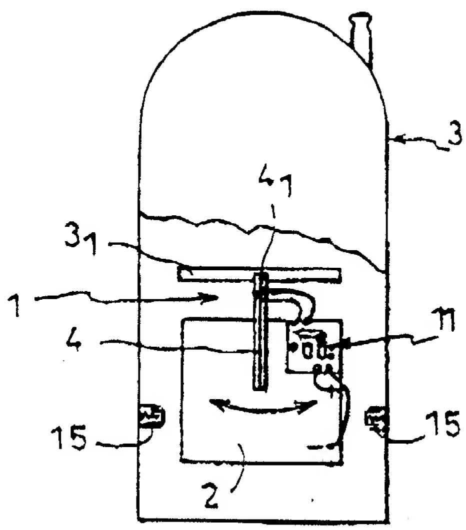


FIG_5

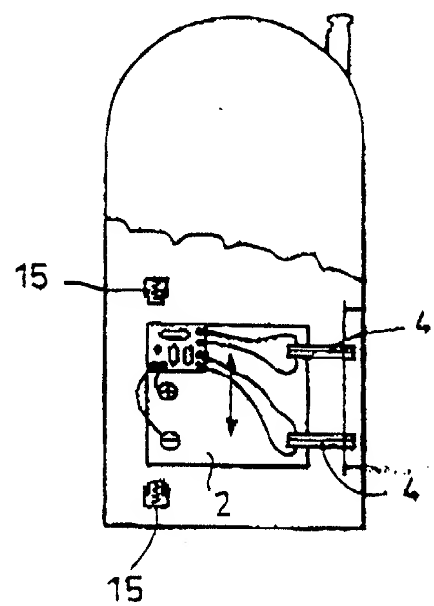
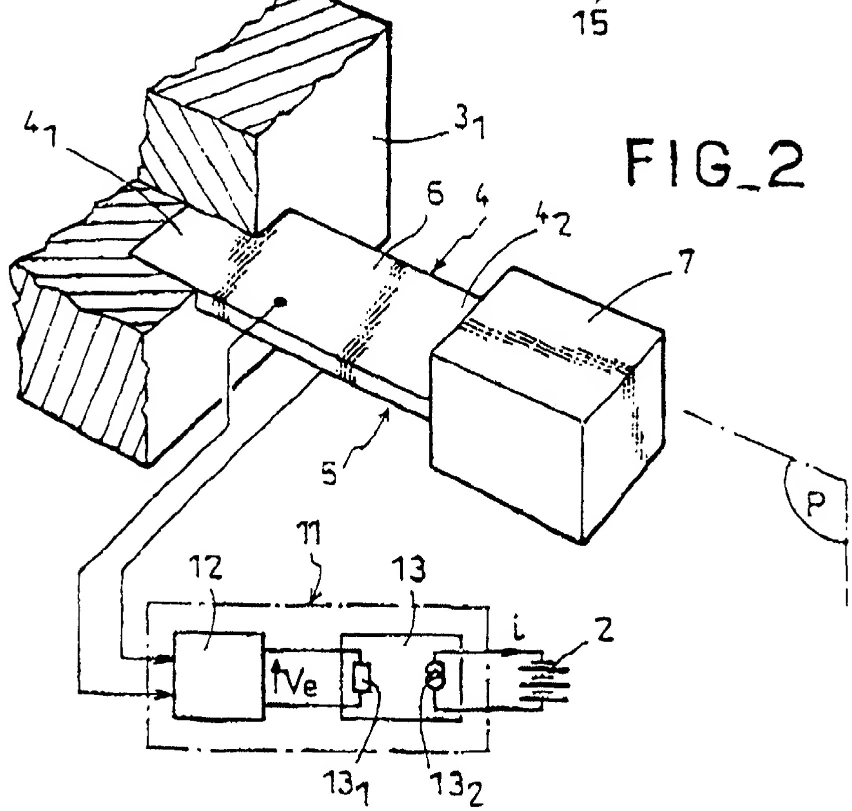


FIG_2



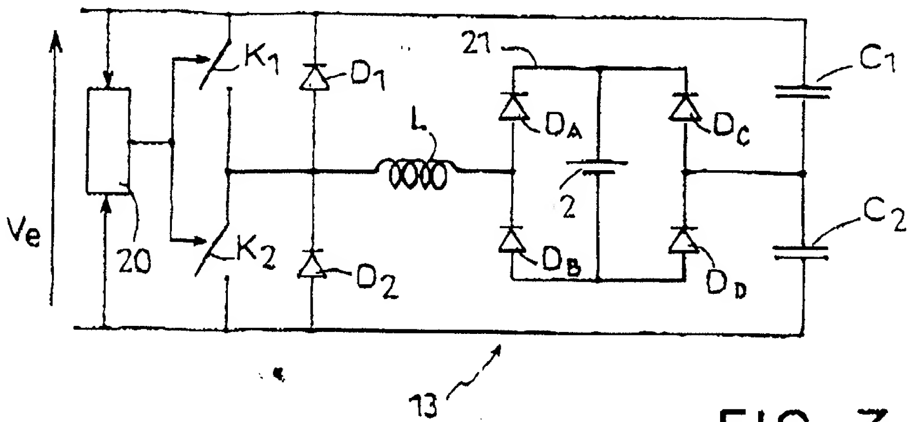


FIG_3

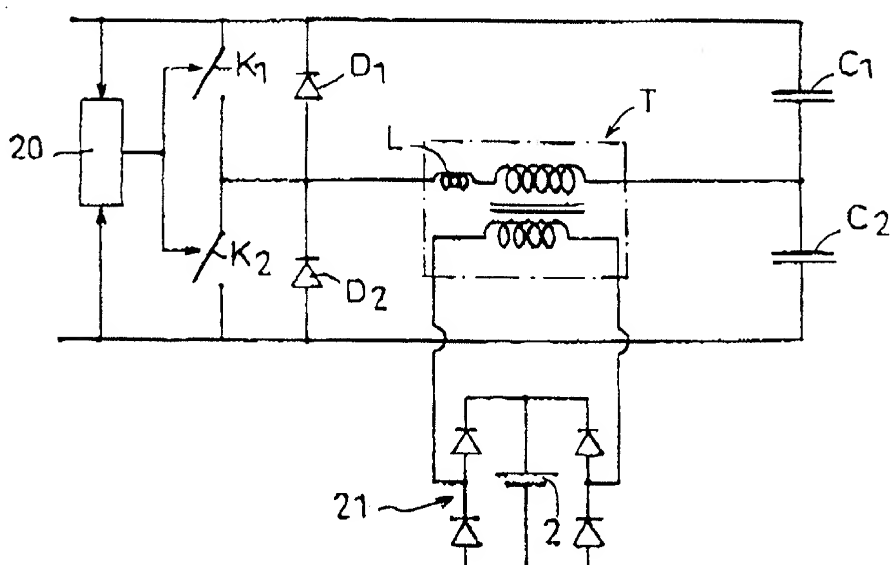


FIG_4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
95 42 0070

Category	PERTINENT DOCUMENTS Identification of the document, indicating if necessary the pertinent sections	Concerns Claim	CLASSIFICATION OF THE APPLI-CATION [*Illegible*]
A	DATABASE WPI Week 7923 Drwent Publications Ltd.., London, GB AN 79-F0844B [23] & SU-A-618 717 (ABRAMOV ET AL), June 24, 1978 * Abstract * ---	1	H02J7/00 H01L41/113
A	US-A-4 870 700 (ORMANNS) * Abstract * * Column 3, line 43 - line 60 * ---	1	
A	PATENT ABSTRACTS OF JAPAN Vol. 18 No. 33 (E-1493), January 18, 1994 & JP-A-05 266930 (BROTHER IND LTD) October 15, 1993 * Abstract * ---	1	
A	US-A-3 456 134 (H. KO) * Column 1, line 65 - Column 2, line 31; Figures 1, 2 * ---		

TECHNICAL FIELDS
SEARCHED (Int.Cl.^{6})
H02J
H01L

This search report was prepared for all of the Patent Claims

Place of search	Date of Completion of search	Examiner
THE HAGUE	June 30, 1995	Helot, H.

CATEGORY OF DOCUMENTS CITED

X: Of particular importance considered alone
Y: Of particular importance in combination with another publication of the same category
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